KACHEMAK BAY
RESEARCH RESERVE
ALASKA DEPARTMENT OF FISH AND GAME
2181 KACHEMAK DRIVE
HOMER, ALASKA 99603

National Estuarine Research Reserve System

The Spatial Distribution of Bull Kelp (*Nereocystis leutkeana*) in the Kachemak Bay Research Reserve

December 2001

G. Carl Schoch
Kachemak Bay Research Reserve
2181 Kachemak Dr.
Homer, AK 99603
907-235-4799
carl_schoch@fishgame.state.ak.us

Abstract

In August 2000, the spatial distribution of *Nereocystis leutkeana* kelp beds was mapped in the Kachemak Bay Research Reserve using low altitude aerial photography. Protocols were adapted from those currently used in Washington State and California for mapping *Macrocystis sp*. Forests. Low altitude aerial photos were taken using a medium-format camera and a light fixed-wing aircraft to produce vertical and oblique digital imagery of individual kelp beds. These images were geometrically corrected and the kelp beds delineated. The polygon data were entered into a GIS so that estimates of areal extent and adjacency can be compared among beds and among years. In 2000, over 30.6 km^2 of kelp forest were mapped in the bay. The same protocols were repeated in 2001 but those analyses have not been completed. Preliminary estimates however, indicate a >10% decline in surface area. This was mostly due to the inundation of rocky habitat by sand over a shallow subtidal bench near the Homer Spit. The variability of each kelp bed area and density will be tracked over time as an indicator of change and kelp community health. We intend to continue these surveys for a minimum of 10 years. This will track kelp bed changes through at least one major cycle of known oceanic variability (the El Nino/Southern Oscillation). The aerial perspective reported here provides a good spatial context to these changes, especially when related to kelp forest changes documented using the same methods in Washington, Oregon, and California. The correlative work stemming from aerial surveys will help focus our experimental studies to determine the mechanisms of observed changes in population size and density. In order to attribute the shifts in spatial patterns to specific agents of change, on-going research by our science staff is focusing on the effects of light limitation, salinity, and herbivory on kelp growth rates.

Introduction

Bull kelp (*Nereocystis luetkeana*) occurs in kelp forests along the Pacific coast from Point Conception, California to the Eastern Aleutian Islands, Alaska and is the dominant surface-canopy kelp north of Santa Cruz, California.

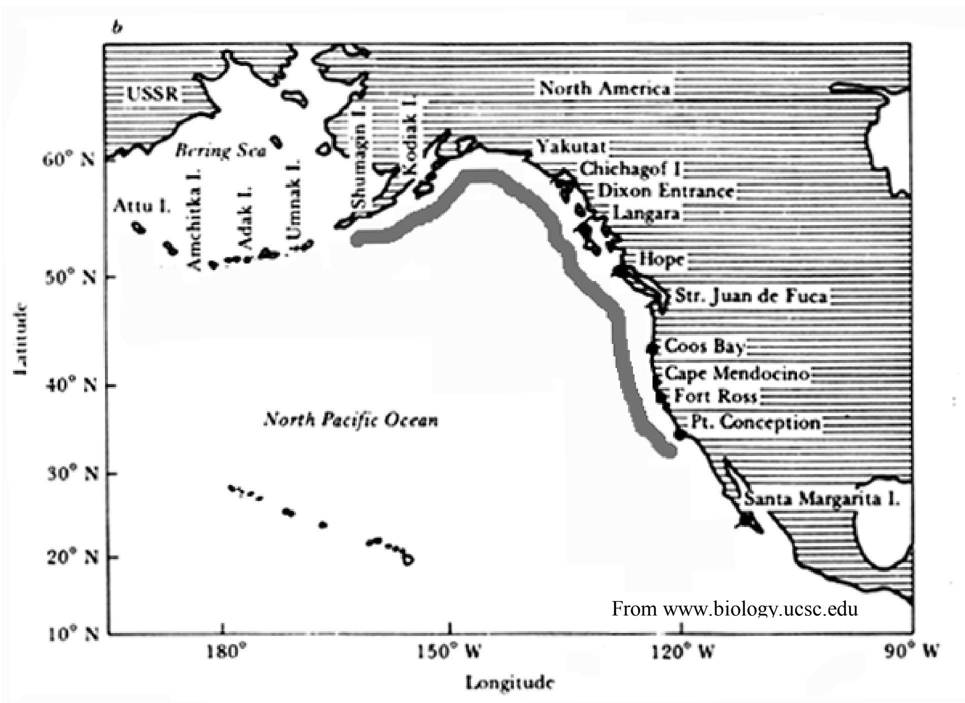


Figure 1. The geographic distribution of *Nereocystis luetkeana*.

Its hydrodynamic shape makes bull kelp especially well suited to high energy, open coast environments. *Nereocystis* is predominantly an annual, although mature plants in Kachemak Bay have been seen to persist for over 2 years. *Nereocystis* is among the largest and fastest growing of the marine algae (O'Clair and Lindstrom, 2001). Growth rates of up to 25cm/day have been recorded. Older individuals are known to obtain lengths over 40 meters during their annual growing season. In Kachemak Bay, growth rates of up to 10 cm per day have been observed in young plants (Chenolet et al., 2001), and the mature surface canopy reaches its maximum extent in July through October.

The areal extent of the total kelp canopy occupied by each of these plants is dynamic from year to year. Annual fluctuations in canopy cover are thought to be the result of a complex combination of physical, chemical, and biological factors. Water motion, temperature, salinity, nutrients, light intensity, available habitat, and invertebrate predation have all been associated with kelp canopy health and development (Dayton, 1985). However, adjacent kelp beds that appear to be exposed to similar physical factors frequently produce vastly different canopy sizes, revealing the complexity of this dynamic habitat. Also, kelp beds are known to have tight trophic interactions. Sea urchins graze on holdfasts that secure the kelp to rocky substrates and sea otters prey upon the urchins. A decline in sea otter populations may release urchins from predation pressure and allow them to graze heavily on bull kelp. Herbivorous snails feed directly on juvenile kelps and on diatom films that grow on adult kelps (Chenelot et al., 2001). The relationships of these individual factors, and identification of those that may be limiting at any time, are not fully understood, and continue to be the subject of ongoing research investigations in Kachemak Bay and throughout the North Pacific.

Background

Much of the following background information on the life history of *Nereocystis* was extracted from the web site at www.biology.ucsd.edu.

Nereocystis favors rocky reefs with swift tidal currents and forms extensive beds on rocks between 5 - 20 meters deep. It is also found as isolated plants in lower tidepools, although growth in these plants is often stunted.

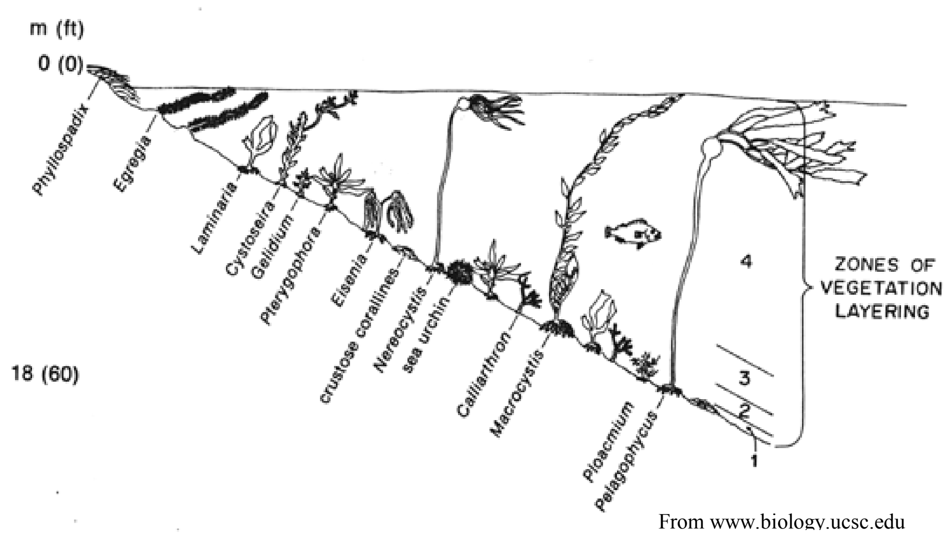


Figure 2. The vertical zonation within kelp forest communities.

The laminariales, or kelps, are in the order Phaeophyceae, or “brown algae. They are unique because the sporophytes form complex multicellular structures or thalli (Figure 3). The major

Figure 3. The sporophyte life stage of *Nereocystis luetkeana*.

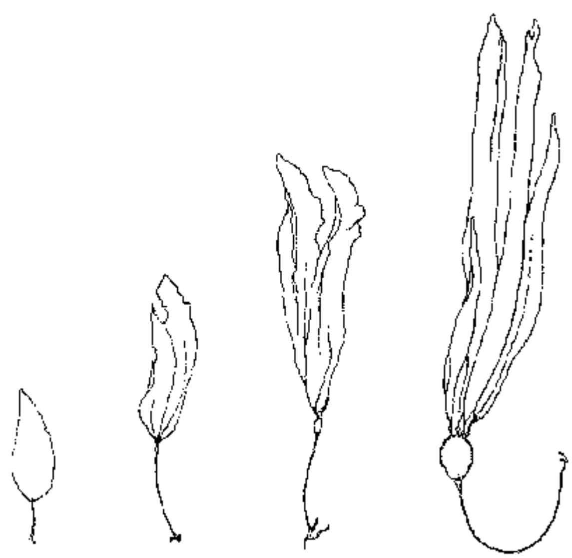
photosynthetic pigments include chlorophylls a, c1, c2, and additionally, fucoxanthin which gives their cells a brown color. The phaeophyceae are divided on the basis of life cycle, growth patterns, macrothallus construction, and sexual reproduction.

Nereocystis undergoes a heteromorphic alternation of generations. In this type of life cycle, there are two major stages: the large conspicuous sporophyte alternates with a microscopic filamentous gametophyte (Figure 4).

Figure 4. The gametophyte life stage of *Nereocystis luetkeana*.

The large sporophyte thallus is produced in early spring and summer, and remains until November or December. As winter storms remove this conspicuous kelp, *Nereocystis* persists as obscure filamentous gametophytes. The gametophytes undergo oogamous sexual reproduction, where the female gametophyte produces a large, non-motile egg which is fertilized by bi-flagellated sperm from the male gametophyte.

After fertilization, the microscopic egg develops into a miniature sporophyte. The juvenile sporophytes emerges from deep water in the spring and early summer (Figure 5).



From www.biology.ucsc.edu

Figure 5. Development stages of a *Nereocystis* sporophyte.

The sporophytes of this family (Laminariales) display a high degree of tissue specialization and structural complexity. The physical structure consists of a holdfast, stipe, pneumatocyst, and the blades. These develop with a distinctive growth pattern where the meristoderm between the stipe and lamina, acts as the primary area of cell production.

Probably the strangest physical feature of *Nereocystis* is the single, disproportionately thin stipe arising from the relatively small holdfast (Figure 6). The stipe directly above the holdfast of a mature plant over 30 meters in length may have a width of only one centimeter.

Figure 6. The holdfast and stipe of a *Nereocystis* sporophyte.

Unlike other kelps, the holdfast of *Nereocystis* is composed of many fingerlike projections called, haptera. These haptera can grow into cracks on rocks, anchoring the kelp to almost any hard substrate (Figure 7).

Figure 7. A *Nereocystis* sporophyte holdfast and haptera on an experimental substrate.

Another distinctive feature of *Nereocystis* is the pneumatocyst, which is used to provide lift to the alga's blades, allowing it to form the dense canopies observed off of the Pacific coast. These are advantageous to the plant by allowing the blades to receive a greater amount of light for photosynthesis. The pneumatocysts can be up to 15 centimeters in diameter and have walls up to 2 centimeters thick (Figure 8).

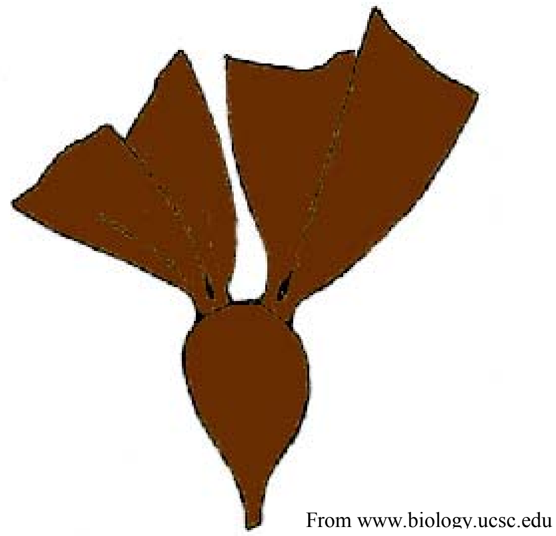


Figure 8. A diagram of a mature *Nereocystis* sporophyte pneumatocyst.

The pneumatocyst tapers off into the apophysis, which can be up to 7 centimeters thick. Together, the pneumatocyst and apophysis have been observed to contain a total volume of 3 liters of carbon monoxide.

Between 30 - 64 blades stem from the mature pneumatocyst of *Nereocystis* (Figure 9).

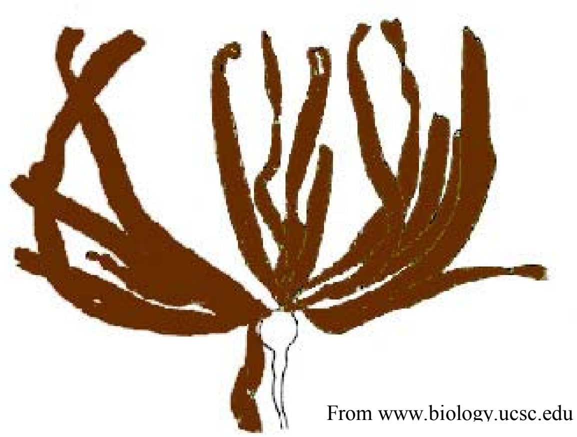
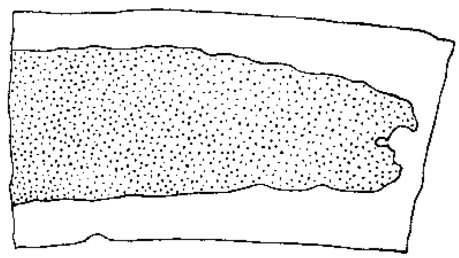


Figure 9. The blades of a mature *Nereocystis* sporophyte.

In the early maturation of the sporophyte, the initial blade develops the first split some time after the rise of the pneumatocyst (see Figure 5). As the plant grows, the shorter stalks of the secondary blades become more separated. Successive splitting of the blades occurs as the stipe elongates. Eventually, these blades can grow to 4 meters in length and be up to 15 centimeters wide.

The blades of *Nereocystis* play a critical role in the release of spores. Each blade functions as a sporophyll and develops reproductive structures known as sori. Sori are usually found on the blades of *Nereocystis* as rectangular patches in linear series (Figure 10). These develop from the base of the blade, and migrate towards the tips of the blades where they eventually fall off and sink prior to the release of spores.



From www.biology.ucsc.edu

Figure 10. A sori patch on a *Nereocystis* sporophyte blade.

The spores develop into male and female gametophytes that persist through the winter and in the spring the cycle starts over. The life history of this alga is summarized in the diagram in Figure 11. From left to right, the mature sporophytes develop sori that ablate from blade tips as they grow away from the pneumatocyst. The sori are carried by the currents and eventually settle to the bottom and release zoospores. These grow into male and female gametophytes that persist through the winter as a short green turf on rocky substrates. The male gametophytes release sperm that fertilize the eggs released by females. The fertilized eggs develop into juvenile sporophytes that rapidly grow from holdfasts to the surface. Once near or on the surface the sporophytes become reproductive.

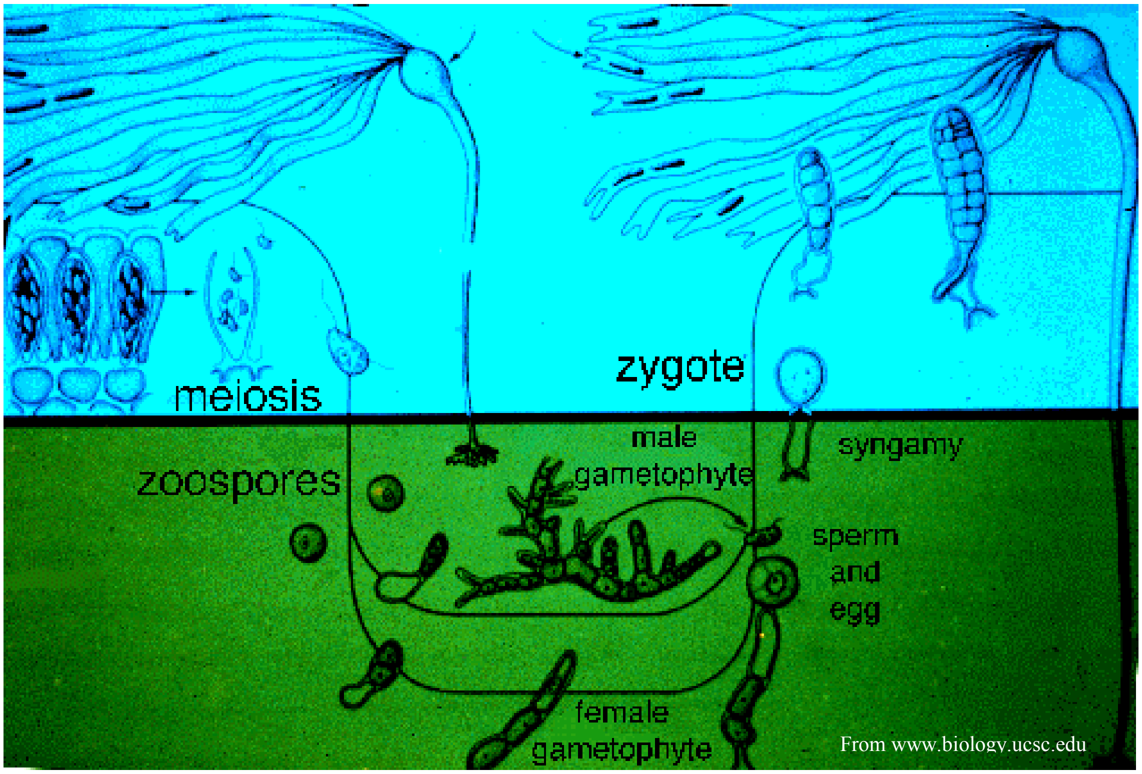


Figure 11. Diagram of the complex life stages of *Nereocystis*.

Although only an annual, the sporophyte of *Nereocystis* serves as the foundation of several communities and plays an important part in the life history of other marine organisms. Several other algal species are epiphytic on *Nereocystis*. These include *Ectocarpus fructosus, Compsonema intricatum, Strebonema scabiosum, Enteromorpha linza* and others. However, the most abundant epiphyte is likely to be *Porphyra nereocystis* which is not found on any other algae. On some second year kelp plants in Kachemak Bay, extremely dense growths of *Porphyra* have been observed on kelp stipes, so that the plant can no longer be kept afloat by the pneumatocyst.

Invertebrates also take advantage of this alga. The nudibranch, *Triopha maculata* (Spotted triopha), lays its eggs specifically on *Nereocystis* and the closely related *Macrocystis*. This alga provides a food source for other invertebrates. These include sea urchins and the isopod, *Limnoria algarum*. In the former, *Nereocystis* has been shown to be the "food of choice", probably because of its high nutritional value. In the case of the latter, the holdfast is eaten, weakening the foundation of the plant. In Kachemak Bay, one of the important herbivores on

Nereocystis is the snail *Lacuna vincta* (Figure 12). This snail recruits from the plankton in early summer. Accumulations of over 300 snails were observed on a 0.5 m juvenile *Nereocyctis* plant in June 2001 (Figure 13).

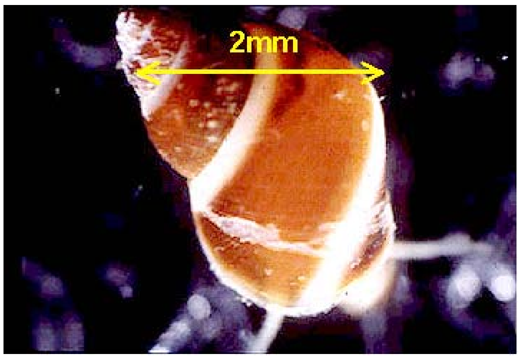


Figure 12. The snail *Lacuna vincta*.

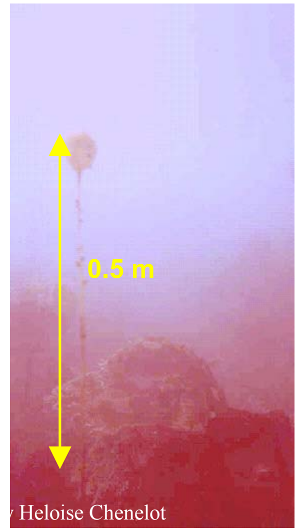


Figure 13. Remains of a juvenile *Nereocystis* following intensive snail herbivory.

Several aspects of *Nereocystis* make it a model alga to study. The massive growth rates of *Nereocystis* may also make it an important bio-indicator. Studies have examined the effect of increased carbon dioxide on the growth of this alga. As carbon dioxide levels steadily increase in our atmosphere, the development of fast growing algae may be seriously affected (Thom 1996).

Methods

In August 2000, the areal extent of *Nereocystis* kelp forests in Kachemak Bay was mapped using protocols developed in California and Washington for baseline monitoring programs (Van Wagen, 1996). The intent was to gather baseline data on the abundance and density of *Nereocystis* in the bay, and to begin studying the mechanisms that affect mortality. The baseline data will help us understand the natural variability of kelp forests from year to year so that this alga, the habitat it forms for other organisms, and the community that results can be evaluated as an indicator of large scale changes in the ocean. The defined scope of work for this project was limited to measurement of current kelp abundance. With one year of data, no temporal comparisons can be made, however, we intend to continue collecting these data in the future so we can better assess the natural variability over time.

The seasonal timing, photographic scale, and flight parameters of the aerial surveys were established to obtain imagery of the representative maximum areal extent of kelp coverage. In Kachemak Bay, the maximum extent of the *Nereocystis* canopy occurs from August to October. Thus the beginning of the aerial survey window is determined by the maturation of the kelp plants, and the end of the window is affected by the decreasing probability of good weather as the summer high pressure system over the Gulf of Alaska deteriorates. Within this seasonal window, only a few suitable low tide periods occur. The best representation of the maximum kelp bed area occurs during the lowest tide, or low spring tide of the month. Only one low spring tide occurs each month and typically lasts for 5-7 days. In 2000, these tides occurred July 28 to August 4 (-0.9 m), August 27 to September 2 (-1.3 m), and September 26 to September 29 (-0.4 m). The late August tide was targeted and the flight was scheduled for the first acceptable weather day within that window. The optimal weather conditions were set for visibility greater than 5 miles, surface winds less than 10 knots,, sea/swell state less than 1 meter, and a sun angle greater than 30 degrees above the horizon. The aircraft altitude during the survey varied between 1500 feet and 5,000 feet. The huge kelp forests on the north side of the bay could not be photographed at altitudes below 5,000 feet. All the kelp beds on the south side of the bay were photographed from 1500 feet.

A Hasselblad 501 medium format camera was used with a 70mm lens set at stop f-4, 1/250 speed, using 200 ASA film. These surveys typically use color infrared film, which is the accepted standard for documenting the areal extent of vegetation. However, infrared film has poor water penetration properties, and this limits the imaging of sub-surface kelp plants. *Nereocystis* canopies in Kachemak Bay are often submerged due to the drag of tidal currents, so we chose to use regular color film.

The aerial photography flights were made on August 30, 2000 from 9–11 am. Continuous sequential vertical and oblique aerial photos with 20-30% overlap were taken of the kelp beds from Anchor Point to Homer on the north side of the bay, and from Halibut Cove to Point Bede on the south side of the bay. The resulting imagery was of excellent quality. The water penetration was approximately 2-3 meters, depending on turbidity. Over 120 images were taken to capture the kelp canopies in the bay.

Base-line maps from this coastal kelp survey were produced from the photo images. Kelp canopies on each image were delineated with a polygon and the entire image was then scanned at 600 dpi (Figures 14-19). ERDAS Imagine was used to geometrically rectify each image. Digital orthophoto quads (1 meter pixels) from the Natural Resource Conservation Service in Palmer, Alaska were used as basemaps to register each scanned image. Once registered, the canopy polygons were digitally traced on-screen using the ERDAS Imagine Vector Module. All canopies consisting of more than two plants were digitized. The canopy map was set to the Alaska Albers Conical Equal Area projection.

Figure 14. Oblique aerial photo of the kelp canopy near Anchor Point, Alaska. This canopy is approximately 1 km wide and 4 km long.

Figure 15. Small kelp canopies off of Hesketh Island, on the south side of Kachemak Bay.

Figure 16. Small kelp canopies off of Yukon Island on the south side of Kachemak Bay.

Figure 17. A narrow band of kelp following the 10 m isobath off of Hesketh Island.

Figure 18. Kelp canopies in the Herring Islands on the south side of Kachemak Bay.

Figure 19. Patchy kelp canopies in Sadie Cove on the south side of Kachemak Bay.

Results

The total area of delineated kelp canopy in the Kachemak Bay Research Reserve was 30.6 km^2. This includes the area of the bay from Anchor Point to Point Pogibshi. An additional 17 km^2 of kelp canopy occurs further out the bay between Point Pogibshi and Point Adam. Although those data were collected and remain on file, that area will not considered for this report.

The most striking aspect of the spatial distribution, as shown in Figure 20, is that the largest kelp beds occur on the north side of the bay. This most likely results from the shallow bathymetry between Anchor Point and Homer. The low slope angle of the rocky habitat in this area, where depths range from 10 and 20 meters, allows a greater surface area of habitat to be available for successful spore recruitment. Interestingly this population may represent the furthest north kelp bed on the east side of Cook Inlet. Other large kelp beds flank the entrance to Seldovia Bay, and a solitary large bed occurs near the end of the Homer Spit. There were no large beds observed in the inner bay beyond the Homer Spit. Two small beds of about 20-30 plants occurred on each end of Gull Island near the mouth of China Poot Bay. Peterson Bay and Halibut Cove each support a number of solitary individuals. A cluster of about 20 plants occurred at Peterson Point near the entrance to Halibut Cove. The Herring Islands group support a number of small kelp beds, but owing to the steep subtidal slope, the beds are narrow and small. The beds appear to be more robust on the south side of the bay, and more so near the bay entrance around Port Graham. These kelp beds were all very dense, forming thick mats on the surface at low tide. Whether this is due to the lower turbidity, higher salinity, or colder temperatures is the subject of on-going research. The lower densities of the kelp beds on the north side of the bay may suggest less suitable habitat, increased herbivory by urchins or snails, or a function of spore distribution by water currents.

In June 2001, over 2000, 3 x 4 inch drift cards were deployed near Point Pogibshi to track the velocity and direction of the currents in Kachemak Bay. The purpose of the study was to find out how kelp spores and invertebrate larvae travel in Kachemak Bay. This drift card deployment was one of 6 releases throughout the summer. The other five releases are not discussed here. Figure 21 shows the release transect, and the recovery points. Note that all of the cards stayed in the outer bay. This was caused by the strongly stratified surface flow leaving the inner bay during the summer months. The cards stranded mostly on the Homer Spit and on the beaches between Homer and Anchor Point. This pattern of stranding indicates a strong cyclonic (counterclockwise) gyre in the outer bay, and an on-shore transport caused by dissipative waves in the nearshore zone along that section of coast. This study, along with the findings of the aerial survey provide evidence that kelp populations on the south side of Kachemak Bay may represent source populations for kelp beds on the north side of the bay. More research will be needed to substantiate this hypothesis, but all indications based on distribution, kelp bed density, plant growth rates (Chenolet, et al., 2001), and herbivory suggest that the Anchor Point kelp beds are at the limit of their range, and thus most prone to changes caused by environmental shifts.

Ground truth surveys throughout the summer months confirmed that the surface canopies of kelp beds in Kachemak Bay were mono-specific and homogeneously *Nereocystis leutkeana*. Prior reports had some plants of another brown alga *Alaria fistulosa* mixed with the *Nereocystis* but this could not be substantiated from the surveys conducted in 2000.

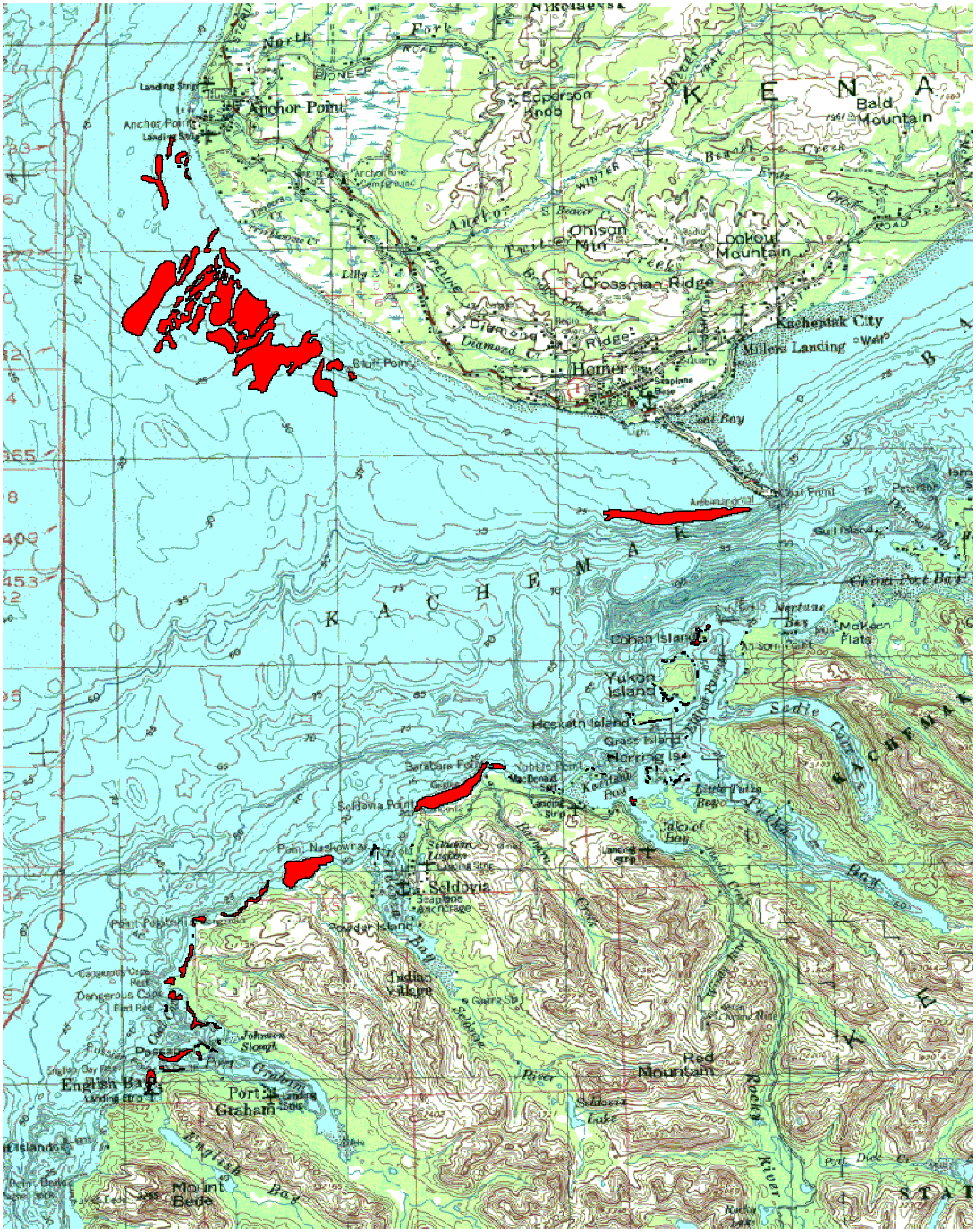


Figure 20. Quantitative spatial distribution of *Nereocystis* canopies in Kachemak Bay on August 30, 2000.

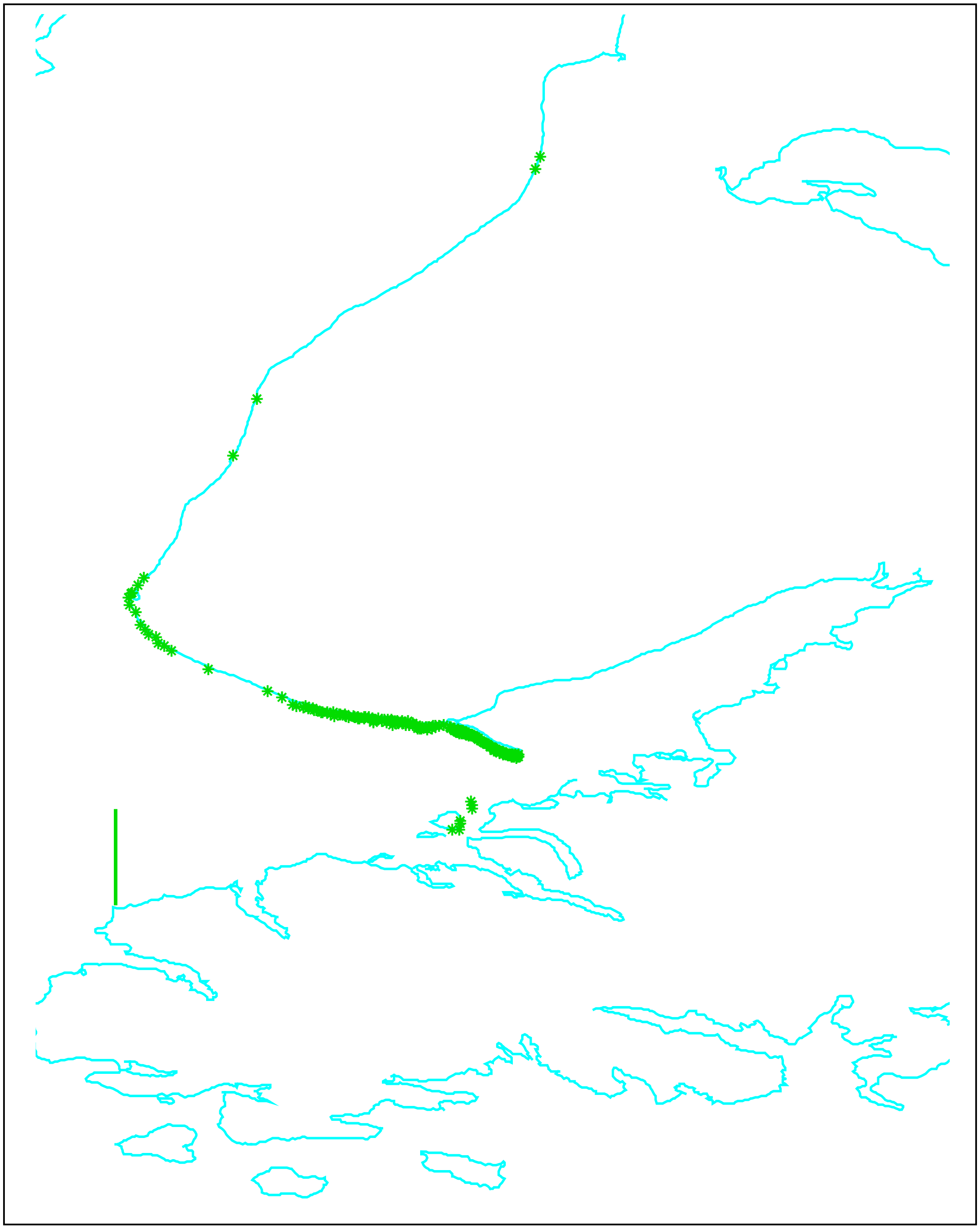


Figure 21. The solid line show the location where 2000 drift cards were released in June 2000 to track the current flow in Kachemak Bay. The drift cards were recovered at the starred locations from 1 week to 1 month following the release.

Figure 22 shows a detail of the kelp distribution GIS coverage for the Herring Island group on the south side of Kachemak Bay. This view is superimposed on a digital orthophoto from the Natural Resource Conservation Service. This is shown as an example of the resolution available from the coverage. Some of the smallest kelp polygons are no more than a few meters square. While this resolution is too high for a meaningful signal of change in the bay, e.g. the natural annual variability is expected to be considerably higher than the mapped resolution, this still provides a useful tool to track the persistence of small kelp populations.

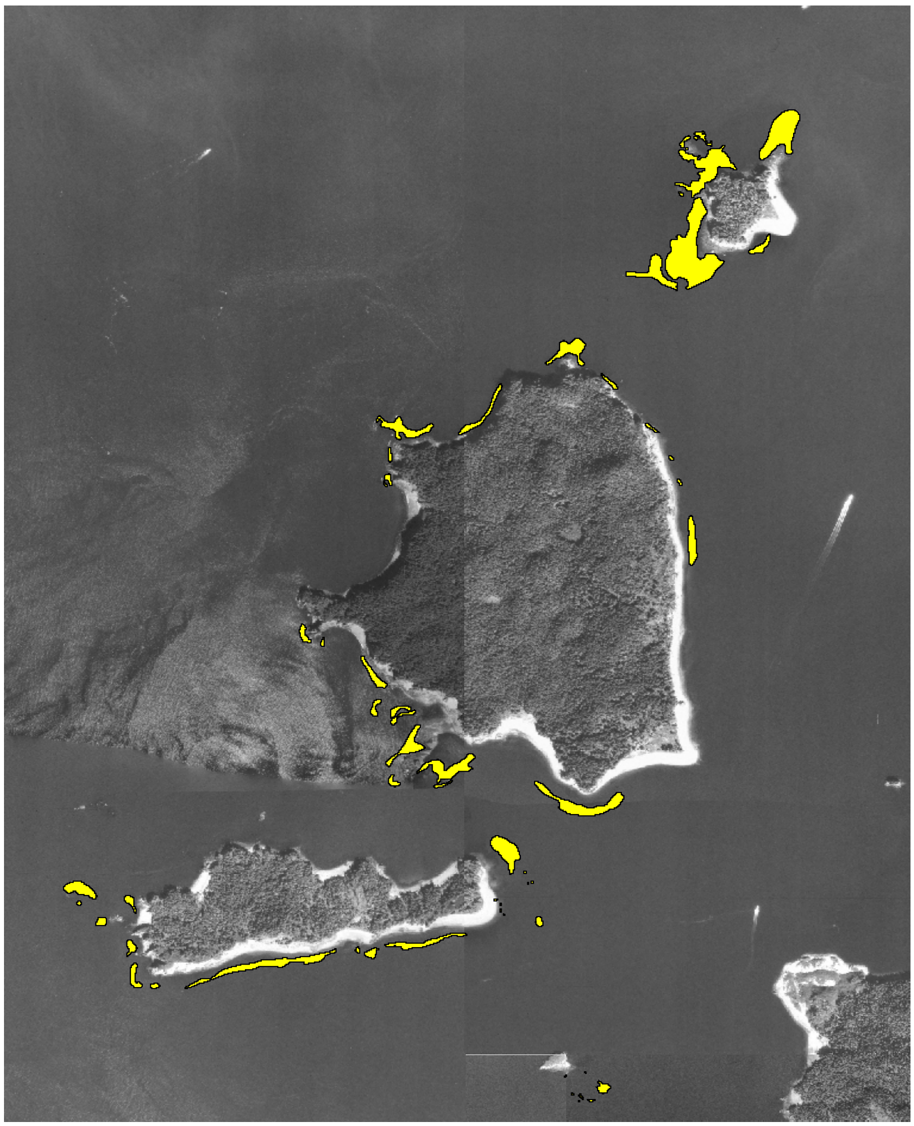


Figure 22. Detail of kelp canopy distribution superimposed on a digital orthophoto of Yukon and Hesketh Islands on the south side of Kachemak Bay.

In 2000, we estimated the plant densities in each major area of kelp beds and produced the qualitative map shown in Figure 23. The majority of the kelp beds on the south side of the bay had high plant densities even though the habitat area available for settlement was smaller. Kelp bed density decreased further into the bay to a point near Halibut Cove where only individual plants were found. No plants were found beyond Ismailof Island. The Anchor Point complex was mostly medium density, with higher density patches along the deeper bathymetric contours.

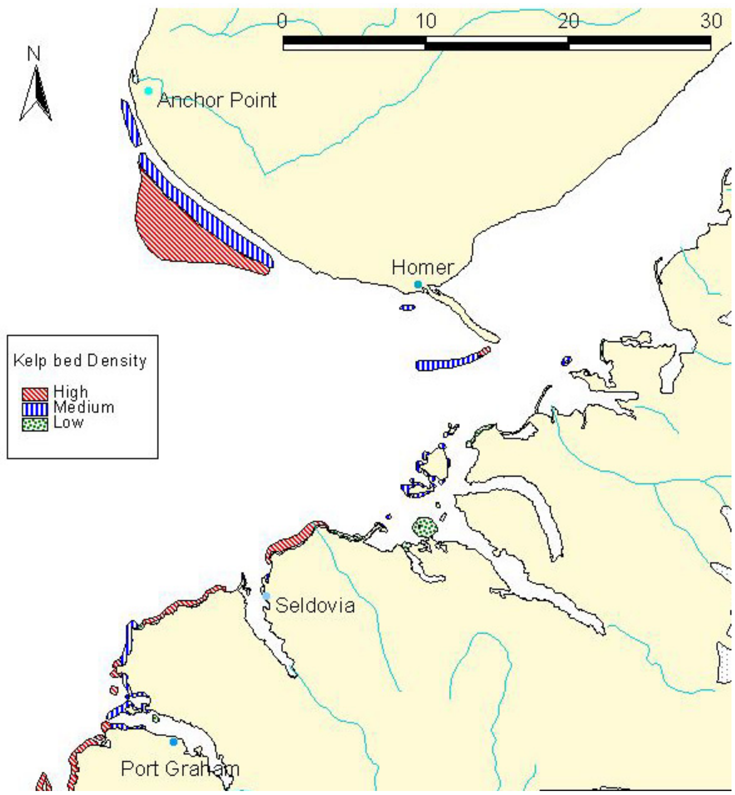


Figure 23. Qualitative canopy density of Nereocystis in Kachemak Bay on August 30, 2000.

Conclusions

The aerial survey, mapping and GIS display of the kelp beds in Kachemak Bay will provide scientists and managers with the first accurate inventory and spatial distribution maps of the Bull Kelp *Nereocystis leutkeana*. The need for these data has recently been expressed in three ways. First, the recent release of another GIS map of kelp beds in Kachemak Bay (Figure 24) appears to be gravely misleading. This widely published map was based on anecdotal information gathered from interviews of local biologists. This data was published as part of the Kachemak

Bay Ecological Characterization in 2001. Agencies have a great need for accurate information about organisms that fall within their management authority. For example, the Alaska Department of Fish and Game is being petitioned to permit harvesting of Bull Kelp in Kachemak Bay. When these permit applications arrive, management agencies must respond quickly. With minimal budgets to generate new inventories, they are often forced to rely on existing information. In this case, the existing maps were leading managers to the wrong conclusions.

Secondly, Kachemak Bay, and perhaps most of Alaska, is heavily invested in resource extraction industries. Opportunities to exploit new markets are constantly being pursued by large and small business entities. As fisheries begin to decline, more pressure will undoubtedly be imposed on the remaining stocks. One example is the work being done to inventory the octopus population in Kachemak Bay. The link between octopuses and kelp beds has recently been made by industry sponsored research, and one concern over publishing highly accurate maps of kelp forests is that this information will be used to generate maps of octopus habitat.

Thirdly, managers of a public resource such as kelp forests will benefit from these distribution maps, but better management practices need to be developed based on an understanding of the mechanisms that drive changes in kelp bed distributions over time. Although much remains unknown, this study showed that the kelp beds on the south side of the bay may be the source for spores that populate the kelp beds further into the bay and on the north side of the bay. The north side kelp beds may represent sink populations since no other kelp beds are known further north in Cook Inlet. It would not be prudent for managers to allow harvesting of the source population until after they have released their spores. Many of the kelp forests in Kachemak Bay seem to persist through the winter. One management option is to only allow harvesting of second year plants.

Even though the 2001 data have not been fully analyzed, preliminary analyses have shown that even the largest of kelp beds are prone to extinction if they occur in areas of substantial sand migration (Figure 25). Further study will assess kelp bed recovery rates following re-emergence of the rocky habitat from under the layer of sand.

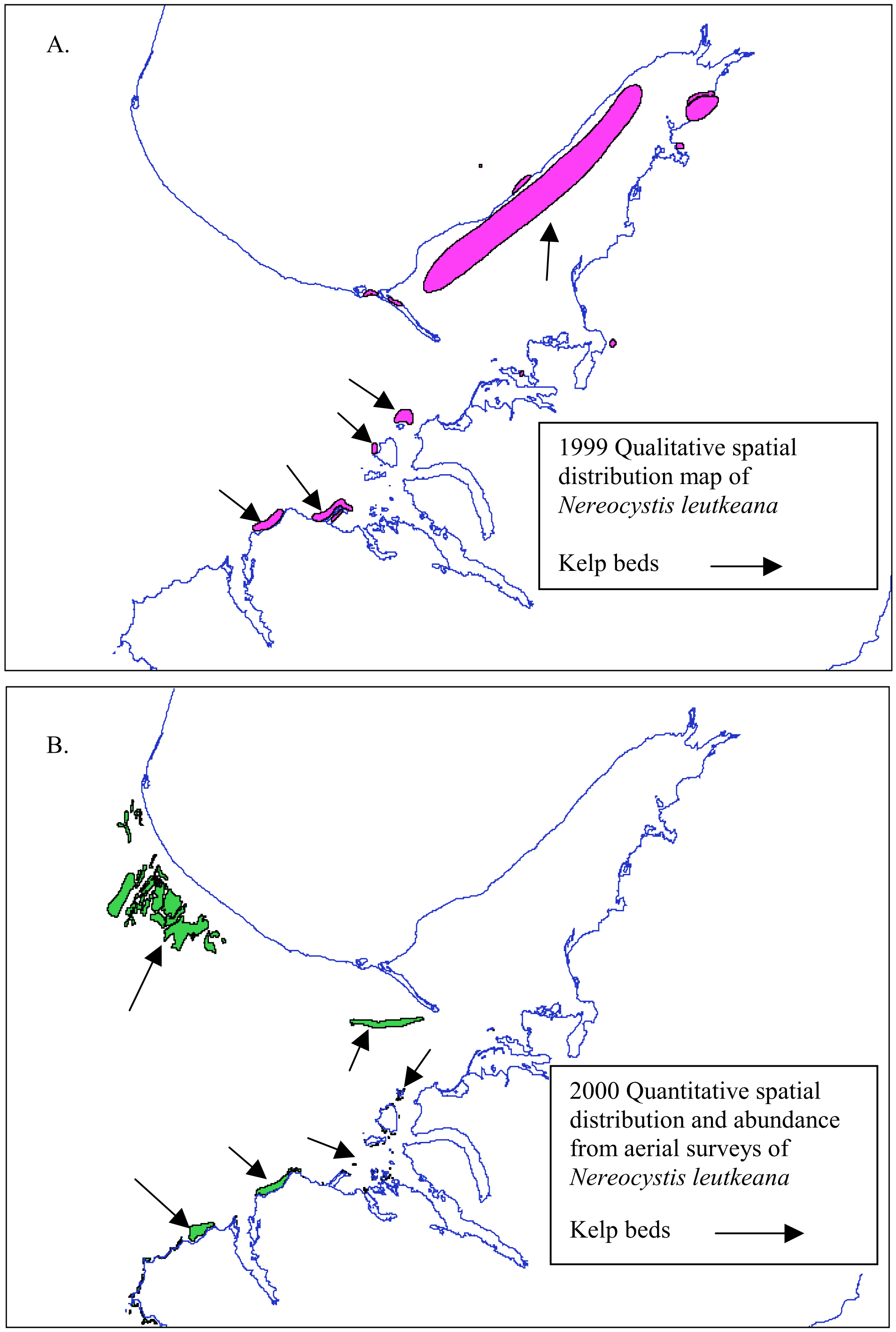


Figure 24. Diagram A is the only other known GIS coverage that includes kelp forests in Kachemak Bay. Note the difference between this coverage published in 2001 (KBEC) and in 2001 (this document), and the coverage described in this report (shown for comparison in Diagram B).

Figure 25. The upper photo was taken during the kelp surveys of 2000. This photo shows a portion of the large kelp bed off of the Homer Spit. Note the distinctive hourglass fishing basin on the spit at the right of the photo. The lower photo was taken in the same area during the kelp surveys in 2001. The kelp habitat was buried by a massive influx of sand during the intervening winter. Subsequent dives in this area to find even a remnant population of kelp, found that up to 2 feet of sand had migrated over the rocky bottom. It seems likely that the sand will continue migrating towards the end of the Homer Spit, and it may be as early as 2002 that the kelp bed will begin to recover. Our aerial surveys will track the progression of this kelp bed recovery as the habitat emerges from under the layer of sand.

Kelp forests are know to provide habitat for a complex array of other marine organisms including rockfish, sea urchins, otters, octopuses, snails, diving seabirds, and a large number of understory algae. There is a well know link between increased secondary production and the proximity of kelp forests (Duggins et al., 1989). Permitting and management of kelp harvesting must consider the long term implications to ecosystem stability. We have established long term monitoring transects in kelp beds throughout Kachemak Bay. The data provided by these sites will help us understand the temporal dynamics of this complex habitat.

Mortality of kelp in the bay is a function of turbidity, salinity, herbivory, habitat availability, and perhaps temperature and nutrient concentrations. These are all areas of future research in Kachemak Bay.


Photo by Heloise Chenelot

Acknowledgements

This study was funded by a grant from the U.S. Fish and Wildlife Foundation under Agreement #701810J306. I thank the Program Manager, John Delapp, for understanding about busy summer field schedules and graciously extending the many report deadlines, Heloise Chenolet for her unfailing enthusiasm as a graduate student and research assistant, Jose DeCreft for piloting the aircraft under less than ideal conditions, and Joel Cusick of the National Park Service for re-projecting the digital orthophoto basemaps.

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